SPAWAR
Systems Center
San Diego

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Advanced Interface for Tactical Security (AITS)

Problem Analysis and Concept Definition

S. A. Murray

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ADMINISTRATIVE INFORMATION

The work detailed in this report was performed by the Sensor Processing and Human Interface Branch of SSC San Diego for the Defense Threat Reduction Agency (formerly the Defense Special Weapons Agency), Alexandria, VA 22310–3398.

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EXECUTIVE SUMMARY

The Advanced Interface for Tactical Security (AITS) project was initiated to improve the task performance of security forces through technology and design improvements to information display systems. The project was implemented in three phases: (1) problem analysis and concept definition, (2) interface design and validation, and (3) communications tools development. This report contains the results of the first phase.

Field observations and interviews were conducted with members of the U.S. Army and U.S. Marine Corps to identify information requirements for tactical security and related missions. Clusters of information needs that emerged from these efforts were then matched with human engineering principles of control and display design to generate a set of functional interface requirements, with an emphasis on performance commonality across tasks. Because military interviews highlighted the need for improved communications, this topic was added to the project as a distinct design focus. Finally, a review of advanced interface technologies was conducted to identify the engineering state-of-the-art, and results were used to select the hardware concepts for the baseline interface system.

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PURPOSE

The primary purpose of this development effort was to design and validate new interface concepts for use by tactical security personnel. A secondary purpose was to fit these results into a larger context of information and visualization support for people whose jobs require a high degree of mobility and equipment portability, and where the demand for information is infrequent.

PROCEDURE

The Advanced Interface for Tactical Security (AITS) project was conducted in three phases:

1. Problem analysis and concept definition, which included
   a. A *functional review* of the job. This step involved field observations and interviews with prospective user communities (i.e., military units with a tactical security mission), with the objective of identifying tasks and procedures, support tools, and personnel factors required to perform the major classes of security jobs.
   b. Definition of user *information requirements*. After analyzing trends in the observation and interview data, we generated a prioritized list of information needs for tactical security tasks. These results were validated by checking them with additional people familiar with the security mission.
   c. Comparison of tactical security needs with those of *other missions* (e.g., military police, site security, surveillance and reconnaissance forces, etc.). This step involved an overview of related security jobs, especially those requiring mobile operators, and was done primarily for completeness.
   d. A survey of relevant *interface design principles* to guide selection of hardware components and display design concepts. These principles were grounded in current human engineering practice and employed the latest design methods for human–computer interaction (HCI), all in support of the information needs of step (b).
   e. A *technical review* of both current and advanced systems that could support the documented information needs of tactical security personnel. Published literature from government, academic, and industrial programs provided a wealth of information on control and display technologies suitable for field use. Candidate technologies were compared with the known working conditions of tactical security forces to prioritize systems according to their desirability for this mission.
   f. Specification of a *baseline interface system* from the range of available interface technologies. Comparing these technologies with the interface design principles of step (d) generated the parameters of the AITS baseline system.
2. Interface design and validation, which included
   a. Developing information *display metaphors* to provide the essential data elements determined from phase 1. These metaphors were implemented in a demonstration videotape, to illustrate their operating characteristics in a sample tactical security scenario. Contents of this videotape will form one of the initial products for user evaluation.

b. Defining and justifying a *test and evaluation approach* for the AITS project. It was important that this effort—which involves demonstrations, user surveys, and structured tests—be documented before system validation began, to ensure that all steps could be mapped to good engineering practice and to the specific needs of the user communities.

c. Conducting the *user evaluation* and interpreting the results. A range of military personnel and security missions was sought for this effort in order to provide diverse perspectives on task demands and technology tools. Results were organized into a final AITS design report, which included general interface principles learned during the development effort.

3. Communication tools development, which included

   a. Defining a voice and data *communications architecture* based on Internet protocols in order to adapt Internet-based communications systems to the demands of tactical military environments.

   b. Developing and testing an *Advanced Data Protocol* (ADP) to support flexible communications between tactical sensors and an operator interface. This protocol supports the direct integration of new sensors into a tactical security network. That is, any sensor communicating over an Internet Protocol (IP) network with the support of ADP tools should be recognizable and readily usable by any interface system in the security network (i.e., a "plug and play" functionality).

Results of phase 1 are summarized in this report. Phase 2 and phase 3 results will be presented in subsequent reports.

FUNCTIONAL REVIEW

USER POPULATION

Four visits were made to units of the U.S. Army and U.S. Marine Corps between June and August 1997 to observe training exercises and to interview personnel about their jobs, their tactics, and their equipment (Blackburn, 1997a; Bryan, 1997; Bryan and Bott, 1997; and Bryan and Gage, 1997). Military police units, Sensor Control and Management Platoons (SCAMP), and regular combat troops were observed in a variety of training exercises, from the squad to the company level. The project team was provided with many opportunities to interview personnel at all levels of command and was able to query people in the field while they performed their jobs. Despite the wide range of missions required of these units, both Army and Marine Corps personnel provided quite common responses concerning the kinds of information required for their jobs, as well as the kinds of information desired in next-generation interface systems.

MISSIONS AND SYSTEMS

The primary missions observed or described during site visits included route and area security, force protection, maintenance of law and order, battlefield circulation control, amphibious assault support, and Military Operations in Urban Terrain (MOUT). An emerging mission discussed by some personnel was protection of signal nodes in a tactical, deployed environment.

Several types of sensors were found in current use, with additional technologies planned for future systems. The Remotely Monitored Battlefield Sensor System (REMBASS) operated by the Army included seismic/acoustic, thermal imaging, passive infrared (IR), and magnetic sensors. The Tactical Remote Surveillance System (TRSS) used by the Marine Corps contained a similar equipment suite. IR sensors appeared to be largely used for counting personnel, while thermal imaging was employed for classifying vehicles. Seismic sensors were used for detection and cueing (i.e., for alerting personnel to the presence of intruders), and magnetic systems were used for counting vehicles.

Sensors are typically managed from a central location, such as a HMMWV or a command post (Bryan, 1997). Mobile troops may be sent from these locations to investigate or confirm sensor events, but do not perform sensor monitoring during such periods. In general, the security task appears to be continuous, active, and manual; although auditory warnings can be used to alert personnel about sensor events, the primary method for detecting intrusions is direct, consistent monitoring of displays by system operators.

INFORMATION REQUIREMENTS

Information needs identified from field observations and interviews fell into three categories:

1. *The intrusion event.* This is the fundamental datum required of any alerting system; i.e., warning information about the presence and nature of an intrusion.
2. *Location information.* Security personnel need to know at least the relative direction and distance to other points in space such as the location of a detected intrusion, a sensor placement, or a command post. When deployed in the field, security personnel and other service members also need to know the expected locations of threats or the direction to other members of their squad.
3. *Communications.* Every security watch or system operator is part of a larger network of data exchange. While communication systems are not the focus of this design effort, the communication systems and methods employed in tactical settings can have a major impact on information displays by supplementing other data, and were repeatedly brought up during the interview process as frequent impediments to effective job performance. Thus, this issue is relevant to interface analysis in that good design can exploit existing communications systems by integrating (or fusing) voice and datalink information into the displays or by facilitating the transfer of such information to others.

THE INTRUSION EVENT

The desired information from a security alert includes the presence (is there something out there?), location (where is it?), and nature (what is it? how many?) of an intrusion. The quality and usefulness of this information depends on both the nature of the sensor (i.e., what it is capable of providing, which may not be everything that needs to be known) and the manner in which the information is displayed. Additional processing or data fusion from other sensors may be required to provide a truly effective alert to the user. The operator currently performs this "fusion" process manually, e.g., by examining and correlating data from a variety of sensors and reaching a personal judgment about the situation. Because the user's information needs—presence, location, and nature—are determined by the security task, and not by the sensor, this process should be automated within the computing engine of the AITS system. Unfortunately, such capabilities will require operational experience with any new data fusion methods, and an iterative development process will probably be required. Displays of raw sensor data, therefore, will probably remain a necessary component of even advanced interface systems for some time to come, at least as a backup option.

LOCATION INFORMATION

Location information refers to both intrusion events and sensor positions. Knowledge about object locations in the environment has always been a fundamental key to successful military operations. A primary function of security personnel is to rapidly determine the location of intrusions in areas under their control. This presupposes that these personnel already know the locations of their sensors; such knowledge helps to correlate detected activity to other meaningful features in the environment, such as roads or defended points, and to infer the significance of an alert. A pattern of signals converging near a tactical node, for example, should draw immediate response from the security system operator, while movement along a wildlife path might reasonably be taken as a "false alarm" or an event requiring further analysis before scarce resources are committed to a reaction.

Currently, intrusion locations are determined manually, i.e., by correlating the location of a sensor source to a point on a conventional chart, and then entering the associated sensor event to generate suspected threat sites. This is a wasteful and frequently error-prone method that relies heavily on the skill of the person performing the task. Combining sensor location with the information that the sensor is transmitting requires little in the way of computing resources and can be more clearly presented as an integrated picture to a system operator, using relatively mature display techniques. Such an approach would provide more rapid and effective security response, and should therefore be considered a fundamental improvement in any new interface design.

Locations of auxiliary elements (as distinguished from momentary intrusion alarms) were also discussed with security personnel, such as regions of current threat and friendly force locations. The purpose of such information would be to provide mobile personnel with a clear depiction of potential hazards and egress routes during patrol operations. Another suggested improvement was information display about the location and identity of mobile radio transmitters (as contrasted with fixed sensor locations). More specifically, it is expected that patrolling security personnel will be in radio contact with other members of their units, and that their information would make more sense to receiving agencies if the location and identity of the communicator were known. Interpretation of a warning about an advancing mechanized column would be quite different, for example, depending on whether the source of the warning was close to or far away from the event. Military police, who frequently exit their vehicles for periodic foot patrols, also expressed a need for directional information to help them quickly find their vehicle again, should hostilities start. No current interface system currently provides such support.

In summary, the value of location information—regarding intrusions, sensor positions, and threat regions—is critical to situation awareness, a factor widely known in the human-factors literature and confirmed during field observations and interviews. Current manual methods for establishing location information, however, are inefficient at best and prone to error. Improvements to presentation formats would do much to enhance the interpretability of current sensor information, and thereby strengthen the task performance of mobile security personnel.

COMMUNICATIONS

A common theme connecting all of the personnel interviewed was the need to obtain and share information about the tactical situation. Every soldier (not surprisingly) wished to know everything possible about the environment, a sentiment reflected in the overwhelming request for better communications. Certainly, integration of interface controls with other tactical communications equipment is a minimal, necessary feature for advanced interface design. Given that every soldier represents a potential surveillance asset, however, then any additional feature that can enhance the sharing of information with others is also a desirable objective for AITS interface design. The ability of a soldier to view data and images sent from other human or sensor resources (including data from remotely operated vehicles [ROVs]) would greatly enhance situation awareness. Additionally, the ability to transmit such information using simple, intuitive interface tools would leverage the intelligence value of the soldier to all other force members. This model of tactical communications treats every soldier as a node in a wider net of shared information. Interfaces that can support the processing, transmission, and display of such information in this way would, therefore, contribute greatly to satisfying the communication needs of tactical units.

Voice Communications

Good radio communications—specifically, a desire for reliable hand-held radios—was the single biggest request from every unit interviewed. This clearly reflected a task perspective and not an explicit interface matter, although good interface design can provide enhanced communications tools relevant to this desire. Voice input devices used to control interface displays and systems could be readily adapted for conventional radio needs, providing hands-free communications in an integrated system.

Both clear and covert communications require support, although not always in the same mission; it is certainly possible to tailor either communication mode to the tasks and working environment of different mission types. Warnings and alerts, for example, could be displayed visually (e.g., a flashing light or digital message) to permit silent data presentation. Presentations of this kind are persistent and have tactical advantages. Digital messages or warnings can remain on the display until they can be acknowledged; the receiver is free to attend to more immediate tasks until the message can be handled, and the sender does not have to repeat the transmission. This technique is already used in other military and civilian systems (e.g., commercial airlines, air traffic control, police cruisers, and taxicabs) to reduce an otherwise large volume of voice traffic.

Data Communications

Many personnel, especially those patrolling in potentially hostile terrain, indicated a desire for a "look ahead" capability, e.g., information from an ROV or other sensor source, prior to entering an area. That is, soldiers would like to obtain all available information about a situation before the situation is directly encountered. However, maximum timely dissemination of available intelligence imagery or other information is essential to supporting such a desire, which implies data (as well as voice) communications.

The tactical value of ROVs or reconnaissance personnel to provide advance warnings could be better exploited if data collected from such sources could be more efficiently distributed. Interface designs that support video capture, imagery annotation (i.e., graphics and voice), and rapid data transmission can form a critical foundation for such a tactical capability. Interface features for data sharing should, however, be controllable with a hands-off, intuitive architecture that does not interfere with soldier mobility or operational safety. Furthermore, the computing module of the interface should support data recording and storage for later transmission when time, position, and security permit.

Data storage and transmission capabilities imply that the advanced interface should, ideally, be designed as part of a larger tactical information network. That is, a flexible means for battlefield data collection and collation could support real-time databases that could also be tapped, just like sensors, for updated intelligence and tactical assistance. Other work being performed for the U.S. Army and U.S. Marine Corps is focused on just such capabilities, so proactive interface design need only permit ready integration of these capabilities into portable display systems when these technologies have matured.

In summary, sensor operators and other security personnel appeared to show good agreement regarding the nature of the information they required and their attitudes about the use of technology to obtain that information. While missions may have differed across units and services, the underlying needs were closely aligned. In general, an advanced interface should provide a capability to correlate the positions of intrusion alerts and sensors, should provide raw sensor data in addition to whatever processed information is displayed, should integrate diverse data sources (e.g., sensor and

map information), and should address flexible data sharing as a fundamental communications capability. The next section expands on these results to address related mission capabilities that might be enhanced through improved user interface design.

OTHER MISSIONS—INFORMATION AND MOBILITY

The AITS project is focused on developing optimal interface controls and displays to support the tactical security mission. As currently practiced, tactical security is largely passive, i.e., the mission involves the *receipt* of occasional alerting information. The security system operator must then interpret the alert and mentally fuse this and, possibly, other information to form a coherent picture of the location, nature, and size of the intrusion. Finally, the operator either responds directly to the event or forwards the information to other responders (e.g., via an update to a map, a verbal report, or an alert over a voice net). Current interface systems, together with available or emerging network technologies, can greatly expand the tools available for the security mission to add new, active dimensions to the task of information gathering and processing. Some of these dimensions are discussed here in order to provide a larger context for the interface designs that follow and to promote innovative thinking about the additional applications of such interfaces.

THE MOBILE USER AS SENSOR

While much of the tactical security job is performed with remote sensing equipment, security personnel spend an appreciable amount of time on dismounted patrol and a significant amount of their sensing job is done by direct observation. Information gleaned from such observation is usually reported via radio or upon return to a base station. However, current network and computer technologies, (e.g., Miller, 1997), support the capture, compression, and wireless transmission of video and other data (including voice), and an interface design that included such capabilities would be of clear benefit to dismounted personnel. The integration of a portable camera, image-compression software, and processing of data at the user site (e.g., GPS location, camera azimuth, elevation, zoom factor, and voice recording), and an appropriate radio would represent a technologically feasible approach to providing this interface capability. Security personnel would function as mobile sensors in this scheme, augmenting the capabilities of other sensing equipment with interpreted, annotated information, and adding to the depth and accuracy of the overall surveillance system. The primary issues to be addressed by the AITS interface design include selection of simple and efficient input methods to accomplish such recording and annotation, and control methods for effecting the data transfer.

THE MOBILE USER AS SENSOR CONTROLLER

The same network technologies that can permit security personnel to receive, condition, and transmit data from remote sensors (i.e., effectively turning personnel into mobile sensors) can allow personnel to take physical control over remote devices (Murray et al., 1998). Certainly, the ability to change the coverage direction of a remote sensor or to alter its operating parameters without having to travel to the sensor site would improve the effectiveness of the overall security system. While the engineering focus of this application lies primarily in the design of the network and communications architecture, the interface design would have to ensure that necessary control functions could be performed without undue burdens, and that display formats did not distract from other activities of mobile personnel.

Because ROVs represent another class of sensor platform, and will be increasingly relied upon for surveillance in future tactical missions (Van Erp, Kappé, and Korteling, 1996), displays of ROV imagery should also be considered for advanced interface design. There is currently great variability in ROV sensors regarding field-of-view, image scaling, orientation and perspective, which complicates the design of appropriate displays. In addition, newer ROV sensors can support real-time digital processing and filtering of imagery by ground stations, increasing the opportunities (and

complexities) of presenting information. Early planning can provide the versatility of interface displays needed to integrate ROV data seamlessly with other sensor information. A further extension of this ROV concept leads to the use of advanced interfaces such as active ground control stations involving a range of capabilities from simple sensor slaving to full vehicle control. Displays for such control are complicated by the need to depict dynamic imagery and by issues of maintaining spatial orientation for the system operator. Special interface features supporting situation awareness of both vehicle state and sensor status will almost certainly be required as well, but the concept holds much promise for active sensor control by mobile forces.

THE MOBILE USER AS COLLABORATOR

Remote sensors, the security operator as an active surveillance source, and the involvement of ROV assets are three types of nodes in the tactical security system. A fourth type of node is the data repository that underlies this system. This perspective formulates the security database as a resource that could be accessed in the same way as any sensor. The ability to interact with data (e.g., acoustic signature files, image histories of a location under scrutiny, data on recent force movements, etc.) would greatly amplify the power of mobile security personnel to interpret or anticipate activity in areas under their responsibility. Because data from all sensors and personnel would presumably be held in such databases, the ability to access data in this way represents a major extension of the concept of tactical security. That is, all security resources would function as a collaborative network, where information from a variety of sources could be retrieved and manipulated in real time to provide each member of the security force with all available information pertaining to his or her task or area, and with contextual information about the activities of other personnel.

The interface design issues for such data access are much the same as for other applications discussed here: the ability to retrieve, annotate, and transmit information quickly and accurately. The semantic nature of database interaction, however, would additionally require the ability to call up or register information based on its verbal description (e.g., by asking for a pictorial history or for any new acoustic files relevant to a sensor hit). Other engineering programs are already developing technologies for such intuitive database interaction, but the manner in which such capabilities are presented to the operator remains an open design issue. How, for instance, do users know that their requests have been understood by the database? How could operators tailor their data search based on preliminary query results? How do users annotate their own data to ensure that storage is in a manner useful to others? While many interface issues need to be resolved in order to support database access such as this, it is important to note that these capabilities are emerging for field use and that security personnel could greatly benefit from their use.

INTERFACE DESIGN PRINCIPLES

GENERAL ISSUES

The literature of human factors and display engineering has much to offer in the way of design principles applicable to AITS. Some of the major considerations and guidelines for system design are introduced here and elaborated in later sections to support initial hardware selection and to outline feasible approaches for information display.

Data Fusion

User information requirements depend on the task, not the technology. What the user needs to know is essentially consistent across the tactical security mission (e.g., intrusion location, distance, classification, etc.), and sensors and displays are merely the instruments to provide that information. This implies that the interface should be designed with a common set of task-relevant information elements; any requirement to interpret different display formats can only add to the cognitive burden of the interface user. A single tactical picture, consisting of all processed sensor information, is the ideal interface for task support.

Data fusion, i.e., correlation of information from different sensors, is essentially a manual task in current surveillance systems. Different sensor types provide different signals, e.g., point source alerts (magnetic sensors), video imagery (thermal sensors), or pattern information (seismic arrays), and each sensor presents this information in a device-specific format. Each system, therefore, must be independently interpreted and, if multiple sensors are reporting signals about the same event, the operator must mentally fuse the results. In addition, some interfaces are complex and difficult to use—training and experience are needed for their proper employment. Clearly, system-level correlation of such multiple signal sources could significantly enhance the clarity and precision of intrusion alerts. Integrated data displays, therefore, represent the major design focus of the AITS project to ensure that the interface is a true *information system*, and not just a display device.

Display Perspective

This topic is related to data fusion. Virtually every soldier needs terrain information for orientation, navigation, and tactical planning. Information can be presented in many different ways that affect its clarity to the user. Graphical depictions of the environment, for example, can be two-dimensional or three-dimensional (e.g., relief maps), and either approach can be presented in self-referenced (i.e., top of the display matches the direction the user is facing) or earth-referenced (i.e., top of the display is always north) coordinates. Display scale is a related factor; the orientation and navigation needs of a foot patrol are very different from those of a reconnaissance helicopter, and attempting to use the same chart scale can either overwhelm or deprive the user with inappropriate detail. Finally, displays can be designed with many different perspectives, e.g., as a static bird's eye view at differing scales, as oblique perspectives (i.e., to show vertical development), or as a ground-level view of surrounding obstacles. Each of these display options has a domain of best use.

A wealth of human performance data is available to guide the design of displays for different mission needs. Paper maps, however, can only include a subset of these data in their designs, which are then fixed (i.e., a particular map must be selected and then used throughout a mission). A better approach is the use of electronic maps, which are becoming increasingly common as military planning tools and tactical navigation media. Such maps can be reconfigured to dynamically support the

current information needs of the user, and should be considered as a critical component of information support for any advanced interface. An additional complication is that useful display perspective may depend on individual preference. That is, significant individual differences exist in the ability of people to interpret spatial information, and different display approaches may work better for some than for others. A good interface, therefore, should provide a recommended baseline depiction, as well as provisions for control of their viewpoint (e.g., scale and rotation) to fit the individual user or the nature of the particular task.

The integration of tactical data and environmental information can generate additional problems for good performance. Tactical symbols can interact with the terrain perspective to affect how clearly the data are conveyed, and poor display designs can interfere with operator understanding. The integration of natural (terrain) and artificial (symbology) information elements to accomplish different tasks is an inexact science and is usually accomplished through an iterative cycle of analysis, user test, and revision. Nevertheless, guidelines do exist, and well-documented testing methods are available that can verify expanded operational capability through improved interface design.

The ability to develop range board solutions for small arms fire—including range, heading, and elevation data overlaid on a terrain map—was a particularly useful example of such an integrated display identified by the units interviewed for this project. Such advanced features, however, must be submitted to comprehensive user testing to ensure their tactical effectiveness before being proposed as common tools.

Information on Demand

A common theme of many tactical interface design where soldiers must operate in potentially hostile regions, or where multiple duties must be performed, is that information should be available clearly and quickly when desired but should not be present at other times (Blackburn, 1997b). The reason for this is that the soldier's senses should be open to critical battlefield events, and not occluded by artificial displays unless the displayed information is critical to mission performance or survival. Displays that are permanently in the user's field of view will probably not be accepted for operational use. The AITS design effort, therefore, is focused on unobtrusive displays that can be brought to the eyes or ears only when needed, and on semi-transparent, see-through displays that allow the user to simultaneously perceive environmental events and displayed information.

Common "Look and Feel"

The ability to integrate new systems with "legacy" technologies (i.e., existing, already-fielded equipment in common use) is a charter feature of AITS design. New products must be usable with current-version systems without the need for retraining users in new interface symbols or functions. Features of the mobile AITS interface effort should share much in common with fixed systems such as those in mobile command posts; that is, the "look and feel" of the interfaces should be similar, whether the operator is located in the field or in a command post. A major barrier to realization of a fully common interface is that many current systems have unique features or display formats that are difficult to match to any alternative interface design. Such interfaces will not just "go away," however, and must therefore be combined in some manner with whatever advanced interface evolves from this project.

Another issue for common "look and feel" is the application of an integrated interface to other military missions. Common systems and designs can generate great cost savings, and multi-application equipment is a valued objective of current military procurement strategies. Commonality

also makes good technical sense in that good, proven ideas in one setting often prove effective in other settings.

VISUAL DISPLAYS

Visual displays provide the primary information channel for virtually all sensor systems regardless of mission, and critical design features of visual displays are discussed in this section. Display capabilities almost never match the performance capabilities of the human visual sense. Nevertheless, capabilities required for essential task support are usually much more relaxed and a variety of technology choices is typically available to meet operational needs.

Field of View (FOV)

"Field of View" (FOV) is the angular extent of a display or the visual capability of an observer; i.e., what a person can see. Larger display areas represent larger fields of view and can present a greater volume of legible information. Binocular human visual capability (that is, both eyes working together) is considerable—approximately 180 degrees laterally and 150 degrees vertically (National Research Council, 1997). Only dome or large-screen projection displays can present information across such a large field. By comparison, a 19-inch (48-cm, diagonal) monitor—a typical size for current workstation displays—has a horizontal size of only 48 degrees and a vertical size of 36 degrees when viewed from a nominal distance of 18 inches (46 cm). While a large display FOV can be useful, it is rarely essential.

Resolution

This term refers to the number of perceivable, or resolvable, elements per unit of visual angle and is a useful measure of image quality; the greater the resolution, the sharper the perceived image (i.e., the greater the detail). Human resolving power, or "visual acuity," corresponds to about 1 arc minute of visual angle in people with normal sight, although this figure varies with image brightness and contrast (e.g., Grether and Baker, 1972). Resolution performance for interface design is driven primarily by the detail of the information that must be rendered, although resolution capability can often be traded off for display size. If an object is too small to depict with the resolution capability of a particular display, a larger display (or image) size must be used. New design approaches based on "virtual" displays are being developed that allow presentation of apparent image sizes much larger than any achievable with more conventional display methods (e.g., Azuma, 1997). Virtual displays have great potential for depicting information of great size and detail since they are limited only by the image generation source, and not by the presentation surface, such as a computer monitor or laptop screen. While virtual displays may be of great use, engineering difficulties (e.g., eye relief, instantaneous field of view) also apply to this technology. Display utility must therefore be evaluated in the context of mission requirements; simpler solutions may suffice.

Brightness and Contrast

Displayed information must be sufficiently brighter than its background or it will not be visible. As anyone who has attempted to view a conventional television in outdoor sunlight will recognize, high ambient illumination can obliterate the contents of a display by "washing out" image contrast. Complex information, such as video or map imagery, requires multiple contrast levels for adequate rendition. Each of these levels, or "gray shades," must be perceptibly brighter than their surrounding, or an observer will not see the full range of information. Dynamic range refers to the total brightness capability of a display, from its most intense to full black (effectively, the background brightness),

and establishes a minimum performance requirement for system design or selection. However, ambient illumination, such as sunlight, sets the minimum background brightness; for effective presentation, the maximum brightness capability of the display system must exceed this background brightness by a level equivalent to the required dynamic range or information will be lost. If brightness requirements cannot be met, then a different display approach must be used or the format of the displayed information must be changed.

Color

Color is an excellent way to organize information in a complex display; color can help an observer find items of interest rapidly (e.g., Sanders and McCormick, 1987). In addition, color is an important coding dimension where multiple data features must be represented in an integrated manner, such as those of tactical maps. There are engineering costs associated with color systems, however. Color displays typically have lower resolution than monochrome displays of equivalent size since three pixels—a color triad (i.e., one for each primary color; Helander, 1987)—are required for every monochrome pixel. Field sequential color-generation methods have reduced, but not eliminated, this problem. For the same reason, color displays are usually not as bright as similarly sized monochrome displays. While the use of color has become common in both military and commercial interfaces—and the benefits of color to display interpretability are largely established—selecting appropriate display hardware to accommodate both color and sufficient resolution is a critical design task for good interface performance.

Symbology

Military forces with high information demands, such as ship task forces or air wings, have attempted to reduce communications bandwidth loads by reducing the amount of voice traffic required for operational support. This has been realized through the use of data links that transmit text or symbol messages. Data-link systems greatly reduce the need for voice circuits and can transfer greater volumes of information across a given bandwidth. Data-link messages can be retained on a display or even stored for later use until the receiver has time to view the information (as contrasted with voice messages, which must be repeated if they are not heard). These communication advantages have driven data-link technology to the level of the individual soldier and make the efficient design of text and symbol formats an important interface design issue for tactical security personnel.

Mobile use of information interfaces requires symbol sets that are clear and comprehensive, and text messages that are short but precise. While large military information systems employ service-wide standardization of symbol and message formats, most tactical displays use symbology sets that are device or application-specific. Because AITS will employ a common display format for all sensors, symbology design is therefore critical to good performance. Performance is especially sensitive to good design if an annotation capability (i.e., the ability to add augmenting information to images or other data transmitted from the field) is provided with the interface, since the soldier must create messages, as well as receive them, using easily generated and easily interpreted symbols.

TYPES OF VISUAL DISPLAYS

Conventional and See-Through Displays

For purposes of interface design, displays may be divided into conventional, or "closed view" systems (e.g., computer screens, which present all relevant information on a nontransparent display surface) and "see-through" systems (e.g., aircraft HUD systems, where information is overlaid on the

real world and viewed through a transparent display surface). While conventional displays are far more common, see-through displays are useful when the real world contains critical information that must be accessible at all times; the see-though display only adds to the natural scene (e.g., Davis, 1997).

Two problems in the use of see-through displays are image registration and image occlusion (Eggleston, 1997). Much of the information presented with see-through displays is meant to highlight or explain objects in the real environment. If an arrow is shown on the display to point out an intruder, for example, much of the information value is lost if the arrow is pointing to the wrong location (a registration problem) or if the arrow is presented over the intruder's location (an occlusion problem). It is essential, therefore, that the information presented on see-through displays be accurately synchronized to the real world, which can be a difficult design issue.

Conventional displays are easier to design than see-through displays because registration is not essential; all information resides on the display surface. Some tactical interfaces (such as the Special Operations Combat Management System [SOCM] described later) employ small helmet-mounted CRTs (i.e., television screens) to present information. However, these displays occlude vision in one eye and force the soldier to choose what he or she pays attention to—the information on the display or the "real world" information coming through the uncovered eye. While innovative design approaches can partially mitigate such problems, there are clear engineering and performance consequences associated when selecting a conventional or see-through display.

Monoscopic and Stereoscopic Displays

Three approaches are used in display design: monocular, biocular, and binocular. A "monocular" display, such as a telescope, presents a single image to one eye, while a "biocular" display, such as a television or computer screen, presents a single image to both eyes. A "binocular" display presents two images, one to each eye (e.g., binoculars). Binocular displays require twice the optics—a set for each eye—as monocular or biocular displays and are therefore more expensive to construct (Task, 1997). Additionally, binocular displays require that both images be matched in terms of focus, brightness, contrast, and geometric distortion so that the user's eyes can synchronize, or "fuse," both images. If the images cannot be fused, then visual fatigue or headaches may result. Because the visual system uses image differences between the two eyes to infer information about depth (i.e., stereopsis), a binocular display is usually necessary to present stereoscopic (or depth) information.

Stereoscopic information has many practical uses in tactical displays. Differences in perceived depth help display users to estimate distance and height, break out hills and peaks in terrain imagery, and break artificial objects out of camouflage. However, because depth perception based on stereopsis falls off rapidly after about 100 feet (National Research Council, 1997) and because monoscopic depth cues (e.g., relative size, occlusion of distant objects by nearer ones, motion parallax, etc.) also provide information for determining distance, stereoscopic information display is usually not critical to task performance.

Physical Considerations

In addition to requirements for optical qualities and image-generation characteristics, a number of other practical engineering considerations must be addressed to ensure an effective visual display (e.g., Perry and Buhrman, 1997). These considerations can often influence system selection more than the issues already discussed.

Weight, Balance, and Bulk. These three factors are critical for both long and short-term wear. Extra weight carried on the body is noticed quickly and, if the weight is not properly distributed, can lead to distraction and muscle fatigue. Body movements such as bending, turning, or running can also lead to injury through inertial forces generated by poorly balanced equipment, and bulky items can be broken or lost through normal activities.

Fit and Adjustability. All equipment used by soldiers provides some measure of adjustability to accommodate the wide range of body sizes inherent in a military population. For the same reasons, visual displays must provide some range of positioning adjustment for comfortable viewing. In particular, head-mounted displays (HMDs) must allow for eye relief (i.e., the distance of the display from the eyes) and binocular displays must allow for variations in inter-pupillary distance (i.e., the distance between the eyes) for different users.

AUDITORY DISPLAYS

Auditory displays have long been used for delivery of warnings and alerts (e.g., Deatherage, 1972). Sound can capture an operator's attention, even when he or she is task-loaded (Sanders and McCormick, 1987; Sorkin, 1987). Furthermore, the auditory channel possesses a wide range of coding dimensions such as volume, pitch, or sequential patterns (e.g., Deatherage, 1972; Wickens, 1984) that can be exploited to provide quite complex information without requiring the operator to look away from current visual tasks. While the use of directional sound is more recent than some other auditory display approaches (e.g., Begault and Wenzel, 1990), its use for orienting the user to location-specific events in the environment represents a powerful new tool for information coding. The objective of advanced interface design is to partition the presentation of information between the visual and auditory senses so that the operator is not overloaded or confused by either display mode.

Disadvantages of auditory displays are intrusiveness and mission security. The compelling nature of sound can be a hindrance if concentration on other information is essential. That is, while visual displays can be ignored by looking elsewhere, an auditory display can intrude on the user's attention at any time. Furthermore, sound must be carefully controlled if mission requirements call for concealment, and while headphones may provide such control, these devices may be objectionable for other reasons. Auditory displays, therefore, can provide performance improvements by tapping a sensory channel other than vision, but their design and use are not always straightforward.

TACTILE DISPLAYS

Yet another method for information display involves stimulating the operator's sense of touch. Tactile displays have an appreciable research history (e.g., Bliss, 1970) and can provide a wide range of information using multiple coding techniques such as vibration frequency, pressure, or location on the body. Tactile stimulation can complement displays for other senses to deliver large volumes of information without overloading the operator.

Most tactile systems rely on stimulation to the operator's hands (e.g., feedback for telerobotic manipulation control), although many body sites have been successfully exploited (e.g., chest, abdomen or back) to provide alerting signals and directional cues. The Tactile Situation Awareness System (TSAS) developed at Naval Aerospace Medical Research Laboratory (NAMRL), Pensacola, FL (Rupert, 1997) is an example of the rich environmental information that can be rapidly interpreted by an operator using only the sense of touch. The TSAS has been successfully used to provide both aircraft pilots and underwater swimmers (e.g., SEALs) with spatial orientation information. Appropriate coding of tactile signals could also provide target classification.

A disadvantage of most tactile displays is bulk or intrusiveness. Tactile displays for the hands usually cover critical portions of the palms and fingers with display elements that can interfere with direct sensing or manual task performance (e.g., Burdea, 1993). Patterns of display elements for other sites on the body must be worn under clothing, and must often be placed directly on the user's skin (e.g., Bach-y-Rita, 1974). These characteristics usually limit the acceptability of tactile displays to applications where their presence is essential, although their potential utility as an information delivery method is considerable.

SYSTEM INTERACTION METHODS

This section presents a survey of control methods suitable for processing inputs for advanced interfaces. Despite several programs of active research, the basic classes of control devices—miniaturized keyboards, panels of function buttons, and mouse devices—have remained the systems of choice for most interfaces (e.g., Greenstein and Arnaut, 1988). Considerable room for improvement exists in the design and location of these devices and in the manner in which functions are mapped to controls. A current thrust in control design is an emphasis on single-handed operation, i.e., permitting use by either hand when the other is occupied. This trend has been influenced by the increase in computing systems intended for field use and by the expanded use of body-worn computers. Primary design issues for these devices are reliable performance and protection from inadvertent inputs during rugged field operations.

Keyboard

Keyboards provide the most comprehensive form of input control since virtually any desired command can be typed in as a function key or as text. However, this approach is time consuming and almost always requires the operator to look at the device to ensure that the appropriate inputs are made. Keyboards are difficult to use with gloves and, because they need physical stabilization, portable versions often require the use of both hands. Special keyboards, operable by one hand, have been designed for body-worn computers, but these small systems possess most of the same disadvantages as larger ones.

Mouse

Mouse devices enable cursor control for designating locations on a display, such as objects or menu items, and are therefore most effective with graphical interfaces. Because the control responsiveness, or gain, can usually be adjusted, mouse effectiveness is largely a function of how well the menu icons are laid out. Mouse-style controls are effective for single-handed use and can be mounted in clothing or on a glove. These controls are rarely included as the only input device to an interface, since many functions such as text composition and data entry are too difficult to support with mouse input alone.

Other Physical Devices

Chordic Panels. Chordic panels involve the use of a small set of special-purpose keys, activated individually or in combination. Although they are usually easier to use than keyboards because fewer keys needed, the set of available options is also smaller. This is normally not a disadvantage, in that most military missions do not require a large range of input capabilities. A practical drawback to chordic panels, however, is that the key combinations are rarely obvious and must therefore be memorized.

Touchpads. Touchpads are sensitive to the location of objects in contact with the display surface and use the operator's finger or another pointing device as a designation control. Touchpads have become a mature technology in recent years as evidenced by the plethora of Personal Digital Assistants. Newer systems can accept input via menu selections or text data written directly on the surface, thus supporting a complete range of operator control. Touchpads do, however, require the operator to look away from the environment to view the display while inputs are being made, and small systems may also require the use of both hands—one for input and one for pad stabilization.

Voice

The use of speech recognition for control of computer devices has expanded significantly over the past 5 to 10 years. While technical problems such as recognition in noisy environments, changes in speech due to operator stress, and limited vocabularies have not been completely solved, this input method has been successfully used in a variety of commercial and military systems for several years (e.g., Gardner–Bonneau et al., 1998).

Voice input is desirable because it is intuitive and does not require operators to use their hands or look away from the environment to effect system inputs. The need for mobile, hands-free interaction with display and communication systems, especially if weapons or other equipment were carried, was apparent from observations of the units visited as part of this project.

Voice control has the same disadvantage as auditory displays, in that sound may compromise a covert mission. The use of voice control as an input method, therefore, should only be provided as a selectable option to permit user flexibility as a function of mission requirements.

Gesture

Interface control using head or hand gestures has also proven effective in many settings requiring alternative system interaction methods (e.g., BioControl Systems, 1994; Starner et al., 1997). Head position, for example, can be correlated with specific regions of a display or objects in the environment, while arm, hand, or finger positions can be used in similar fashion as large "stylus" devices for more precise control. These input methods are based primarily on EMG, or muscle signals and require special equipment to measure body positions. Measurement equipment and cables, therefore, may be just as cumbersome as conventional input methods. The primary benefit of gesture control is that it is intuitive (e.g., pointing or looking at an object) and does not require the user to hold or stabilize a physical device.

Eye Control

A more complex extension of gesture control is the use of eye movements to achieve system input. Tracking the direction of gaze, i.e., eye position, has grown more accurate and robust in recent years and eye control is now a realistic method for supporting computer use by the physically disabled (e.g., Howarth et al., 1992). This approach uses the eye as a cursor controller and, in connection with blinks or other inputs, provides all of the functionality of a mouse device without the use of the operator's hands. The disadvantage of this approach is accuracy deterioration over time. The mapping of eye position to locations on the display can change as the eye tracking device shifts through use or temperature changes. Therefore, eye control is probably not a promising approach for hands-free control in the near term, especially when compared to other input methods.

Other System Issues

The following factors do not fit readily into the preceding categories of design topics, but are nevertheless important in system-level concerns for effective interfaces. These topics are offered here for completeness.

Gain and Volume Controls. The considerable range of light and sound intensities in field environments obviously calls for controls to vary the gain or volume of displays. An automatic function to perform this job would be of great benefit in operational situations, where task loading may be high, but individual adjustments—whether automatic or manual—are always basic components of any complete design.

Annotation Capabilities. The concept of the operator as a system sensor and team collaborator, introduced earlier, implies a user requirement for processing and transmitting information. These tasks, in turn, imply the need for an annotation capability, i.e., the ability to write, highlight, or modify information. If this role is anticipated for mobile operators, then the need for annotation capabilities will influence the selection of input methods since certain control approaches can support these functions better than others.

DESIGN CONSIDERATIONS FOR INFORMATION SUPPORT

These issues were introduced earlier. They are amplified here in terms of their design implications for the AITS baseline system.

Location Information

There are three basic inputs for calculating location information: (1) the operator's geographic position in the environment, (2) the locations of other important objects in the environment, and (3) where the operator is looking. This information can be generated as follows.

Operator Location. Obviously, operators need to know their location in the environment in order to orient themselves. Such information can be provided by Global Positioning Systems (GPS), which are currently small enough for each soldier to carry with field equipment or integrated into body-worn systems. Use of GPS is not considered a risk issue for AITS development, although the problem of GPS signal loss under mission conditions needs to be addressed.

Object Location. To carry out mission tasks, soldiers also need to know the locations of other objects in their environment, such as suspected intrusion points, remote sensor placements, and the positions of other soldiers and "safe" points (e.g., command posts, friendly territory, etc.). The locations of fixed positions, such as command posts or sensor placements can, of course, be directly designated in map databases, while dynamic position marking for soldiers and mobile equipment (e.g., vehicles, ROVs, etc.) can be achieved in large degree with the use of GPS modules. Regardless of the method employed, positions must be conveyed to the user, which means that a data exchange capability will be an integral part of the AITS interface design.

Head Position. The utility of see-through displays, which show task-related information registered directly over the natural environment, was introduced earlier. If this interface approach is to work, information about the position of the head (i.e., the direction of the operator's gaze) is essential. Several HMD systems have been constructed for the dismounted soldier, such as Land Warrior and Data Sentinel. Most systems employ some sort of magnetic or inertial sensor, embedded in a head-worn apparatus, to generate head position information. While performance is satisfactory, additional computer correction is usually necessary to obtain precise data registration (e.g., Azuma, 1997). A

design challenge for the AITS project—where cost is an issue—will be to identify the operational tolerances associated with relaxed registration standards (i.e., how far can registration deteriorate before it affects performance?).

Data Fusion

The personnel interviewed for this project expressed a preference for viewing raw sensor data rather than relying on computer-processed information. This response may have been due to poor display designs associated with some current sensor systems. Marine Corps personnel, for example, noted that considerable training and experience were required to interpret their seismic sensor displays and that good operators could be held in their billets for years to take advantage of such experience. Such stories are indicative of poor interface designs, and good display designs might eliminate this bias toward raw sensor data.

The baseline AITS design will feature raw sensor data display as a supplement to more integrated graphical formats (i.e., as a backup or amplifying source of information). The test and evaluation cycle may show that such displays are, ultimately, not required. They will nevertheless be a part of the AITS until their value is empirically determined.

There is much more to information management than just delivering data to a display. Typically, each sensor type (e.g., thermal, seismic, video, etc.) is characterized by its own display format, and correlating information across sensor types, must be done manually. This process could be greatly simplified if common display formats were used across sensor types or across sensors obtained from different manufacturers. This is unlikely to occur, however, given current acquisition strategies and fluctuating mission characteristics, and common display formats will have to be achieved at the AITS interface. An objective of AITS design is to develop fused information formats that are common to a variety of sensors and sensor types. Such designs place the smallest perceptual and cognitive loads on the operator and are, therefore, the easiest to use.

Status Monitoring

System status alerts and limited diagnostics are a part of most military equipment since changes to equipment function can significantly impact how the operator performs his or her tasks, or how signals from remaining systems are interpreted. System status monitoring is especially critical in security applications, which are characterized by low event rates. Continuous information is needed about the operating status of sensors, for example, to ensure that an absence of information is uniquely due to an absence of intrusions, and *not* to failed sensor equipment.

Communication Support

Earlier discussions regarding the role of the dismounted soldier as a sensor and collaborator highlighted the importance of communications considerations on interface design. However, the interface tools for control and display of information are dependent on the desired degree of communications functionality. If the security system operator needs to transmit data, such as sensor imagery, then the interface controls must be capable of selecting the desired images, annotating them, and confirming their successful transmission. If text transmission is needed, then input devices must be included that can support this task, as well.

Direct sensor control is a potentially valuable feature to support the security system operator. For example, the operator may desire to actively pan a sensor, rather than to wait passively for a sensor alert. This capability would require control devices—including data communications—that are easily

integrated with other interaction tools of the AITS interface. While this complicates the AITS design, such control functionality would support important new missions for the dismounted soldier, such as unmanned aerial vehicle (UAV) or ROV control.

Data Support

If the security system operator can record and annotate events or images, as described above, then sufficient data storage capacity must also be provided in the mobile equipment. Data storage capability is expanding rapidly, and this technology is not considered a critical issue for AITS hardware. Interface design, however, is impacted by large data storage needs in that the operator must be provided with information display formats to quickly review and retrieve stored information such as image or map files, file status, message histories, etc.

An additional function that must be supported by AITS is interaction with remote databases. For example, geographic or intelligence information may be required to supplement current sensor data. Conversely, the operator may wish to update central databases with current sensor data to maintain a common tactical picture among all security participants. While these functions have not been fully defined within the overall security operator concept, appropriate human engineering data are available for addressing the consequent interface support features.

A growing interface concept, found in public service and industrial maintenance applications, is real-time access to technical databases or to human-operated "help desks" while the operator is moving about in the field. This functionality is similar to the database applications just discussed, although with increasingly dynamic characteristics. Again, human engineering guidelines already exist for effectively supporting such functionality, if this interactive capability is desired for tactical security operations.

Physical Durability

A plethora of military anecdotes all support the observation that equipment usually fails when it is most needed. Because so much depends on interface performance during security operations, considerable effort must be invested in the design of alternate and backup interaction methods (i.e., support for "graceful degrades"). Status monitoring was described earlier as one contribution toward robust operation and designing alternate control methods is another. Providing a hand-held or other backup display, for example, can accommodate failure of the primary display device. The task is then to organize these input and display methods into a conceptual architecture and to specify the role that each is to play.

"Plug and Play"

A central theme of the AITS project is versatility (i.e., the operator interface should support both current and future sensor systems, in both normal and degraded modes). The primary approach for achieving this "plug and play" objective is to make the sensor effectively transparent to the interface. That is, *interface metaphors are designed to support the perceptual and decision-making tasks of the operator, not to merely transfer raw data from the sensor to the display*. Considerable data processing may be required by the interface system to achieve this apparently simple goal of consistent display features across sensor systems.

A communications protocol for this purpose is part of the AITS design concept. This protocol involves (a) a method for communicating detection information from the sensor to the interface system, (b) a method for formatting this information on the visual display, and (c) a method for

identifying and characterizing new sensors to the interface. The last component most closely fits the popular definition of "plug and play" by supporting the ready introduction and integration of new sensor technologies into an existing sensor suite.

OTHER SYSTEM SUPPORT ISSUES

A final set of practical selection factors is listed here for completeness. None of these items represents a risk issue for AITS development. Rather, these factors may be used to compare alternative technologies, thereby providing an engineering basis for component or vendor selection decisions.

Standardization

This implies the maximum use of Commercial Off-the-Shelf (COTS) or Government Off-the-Shelf (GOTS) components. Standardized interfaces and software are also desirable, to avoid the "stove pipe" consequences of building or buying special purpose components.

Growth Potential

Systems that are used by a variety of communities and that have an established user history are preferred because vendor support and recurring upgrades are more likely to be available.

Power

The field applications of AITS require portable power sources. Battery size, weight, and effective battery life are all critical issues for system selection.

Cabling

The use of AITS by the dismounted soldier means that AITS equipment must be used in proximity with other gear. The number, size, and routing of cables are a concern because broken cables can render equipment useless under operational conditions, and because fouled connections must be corrected on-the-move.

Cost

Cost is an eternal concern.

TECHNOLOGY REVIEW

This section presents an overview of current and emerging interface technologies for AITS, beginning with the most critical component, the visual display. Each technology—either a commercial product or a prototype—has some level of user experience to document its effectiveness. However, this review is only intended to illustrate the wide range of choices available since the accelerating rate of performance improvement would quickly make a definitive review obsolete. The systems described here serve to show current capabilities and future trends—the major direction being the increased shift to integrated (combining input, processing, and display tools), body-worn equipment for mobile information support.

The review concludes with a baseline selection of technologies for the AITS prototype system. This initial concept definition best meets the information support needs for the basic tactical security mission while providing the potential for mission growth, as addressed in the Other Missions section.

VISUAL DISPLAYS

Portable visual displays can be carried in the hands or worn on the head. Hand-held displays are available with a wide range of features, are relatively rugged, and can be stowed when not needed. However, these displays must be set up on a firm surface for viewing or held with one or both hands. In addition, they require users to view them directly, diverting their eyes from the environment around them.

Head-mounted displays, or HMDs, are typically smaller than hand-held displays and, because they are worn directly in front of one or both eyes, do not require the user to look away from the environment. Potential difficulties with HMDs are that they are obtrusive (i.e., mounted in front of the eyes, possibly with special head gear) and can fatigue the eyes through long use (Task, 1997). Most HMDs are conventional or "closed view" systems (i.e., information is displayed on an opaque surface and the user cannot see anything else beyond it). For this reason, conventional systems are usually configured for only one eye, permitting the other eye to see the real world.

The major alternative to conventional HMDs, introduced earlier, is the see-through display, where computer-generated information is presented on a semi-transparent surface, much like a pilot's HUD system. This approach does not interfere with the user's binocular vision as much as a closed view display, although the required optical components reduce light transmission to the covered eye.

There are three methods of referencing information for display to the user: head stabilization, world stabilization, and body stabilization (Billinghurst et al., 1998). Most HMD systems are head-stabilized (i.e., information remains fixed in the field of view regardless of where the user is looking). This direct approach effectively provides a small computer monitor in front of the user's eye and is employed where information *availability*, such as access to target data, procedure checklists, or diagrams, is the sole criterion for job support.

World-stabilized displays employ additional computing algorithms to determine the location and orientation of the user's head in order to synchronize, or "register," the computer information with the real-world scene; information is anchored to the world, rather than to the user's head. This approach is also known as "augmented reality" because task-relevant, or augmenting, information is always coupled with the view of the real world. Establishing and maintaining the necessary image registration, however, adds to system cost and complexity.

Body-stabilized displays extend world-stabilization methods to surround the user in a richer information environment. Information can be anchored around the user at locations that do not change as the user moves. A display of a technical manual, for example, might be positioned to the user's left, just as a real manual might be placed on a table. The information would come into view on the HMD whenever the user's gaze lined up with that location. A body-stabilized display, however, would allow users to "carry" the table with them (i.e., the manual would always remain to the user's left, regardless of where he or she moved in the work area). Augmented reality displays using body stabilization can make a considerable volume of information available to the user, since positioning of data sources is not limited to the physical workspace in front of the user.

A wide range of color and monochrome displays is commercially available. Monochrome designs, described earlier, are typically brighter than color displays and monochrome see-through systems can pass more light from the real world to the user's eye. VGA-quality resolution is now common in the marketplace (i.e., displays can render the same amount of information as a conventional computer monitor). Fields of view for commercial systems are typically 25 to 30 degrees (horizontal), although some units can achieve over 60 degrees.

Hand-Held Displays

Hand-held devices have a significant commercial base, primarily in the form of palmtop computers and personal digital assistants (PDAs). Most systems employ compact keyboards and mouse devices (e.g., figure 1) while others use touch-panel technology or special stylus tools (e.g., figure 2).

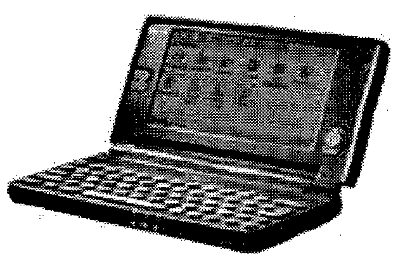

Figure 1. Keyboard input.

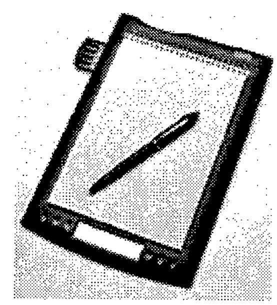

Figure 2. Stylus-based input.

Hand-held displays can be made brighter than head-mounted devices because of their larger size, surface area, and power. In addition, hand-held displays are easier to position for good viewing. However, association of the information with corresponding elements of the environment is more difficult with a hand-held device because the user must develop situation awareness by transitioning from the display to the real world and back again.

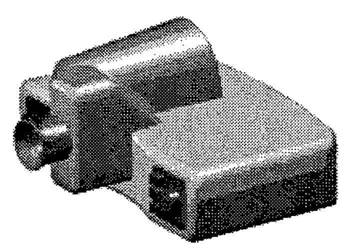

Figure 3. Hand-Held and Body-Worn Graphical Display System.

The Hand-Held and Body-Worn Graphical Display System, developed by Honeywell Technology Center (HTC), is a "transition" device that combines features of both hand-held and head-mounted see-through displays. The system (figure 3) is carried on the wrist or held in the hand and raised to the eyes only when needed. The current design includes a 640 by 480 pixel active matrix electroluminescent (AMEL) color display and can superimpose imagery and graphics over the real world like

other see-through devices. A future improvement planned by the HTC is transmission of display data to an external computer, which would make it a portable information assistant (a class of device discussed later in this report).

Head-Mounted Displays

While early head-worn displays relied on miniature cathode ray tubes (CRTs), current products are almost exclusively based on liquid crystal displays (LCDs) or electroluminescent (EL) technology. LCDs are smaller and lighter and require less power to operate. Modest commercial systems can support at least 1/4 VGA standard (320 by 240 color pixels), although full VGA (640 by 480 pixel) and SVGA (800 by 600 pixel) capability are becoming increasingly common. Active matrix liquid crystal (AMLCD) and active matrix electroluminescent (AMEL) devices have achieved even better performance in the laboratory (e.g., 2560 by 2048 pixels). Selection decisions are usually based on brightness, resolution, field of view, and electronic standard for the input signal (i.e., NTSC or VGA). NTSC displays require a scan converter to operate with most computers, thus involving additional hardware components.

i-glasses. This introductory, low end, head-worn display (figure 4) employs two LCD systems for either see-through or immersive operation (by using an opaque cover). Each LCD features relatively low-resolution (263 by 230 color pixels) and a horizontal field of view of approximately 24 degrees. Displays can overlapped and, by presenting half of the scan lines to one eye and half to the other (a technique known as field sequencing) true stereoscopic rendition is provided. Depending on the on the model, the i-glasses system can accept NTSC, VGA, or PAL signal inputs. Low cost has made this display popular for both entertainment and laboratory use.

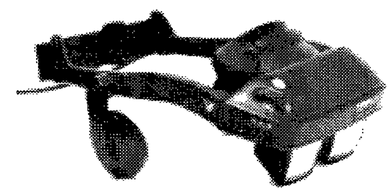

Figure 4. i-glasses.

Sony Glasstron™ Series. The Glasstron™ series of head-worn, see-through displays is relatively new. The PLM-S700 system (figure 5) supports a 31-degree horizontal field of view with 832 by 624 SVGA color pixel resolution (currently the highest available with commercial LCD technology) using an NTSC or SVGA input. The PLM-A55 offers 800 by 225 pixel resolution and requires an NTSC input signal. It is slightly larger and heavier and appears to be directed more toward the home entertainment market.

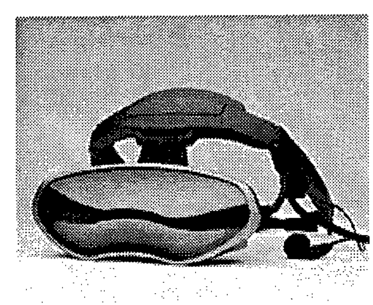

Figure 5. Glasstron display.

ProView™ Series. The ProView display series is available in several models. This product line, generated for a variety of industrial and military applications, uses active matrix LCD technology and is night-vision (ANVIS)-compatible. Each LCD can present 640 by 480 color pixels with a 24-degree horizontal field of view. Total field of view is adjustable through variable overlap of the LCD elements, also supporting stereo viewing. Most models are available with see-through optics, as shown in figure 6, and can accept either VGA or NTSC inputs. ProView systems are designed to allow peripheral vision to either side of the display, so the user can perform other tasks.

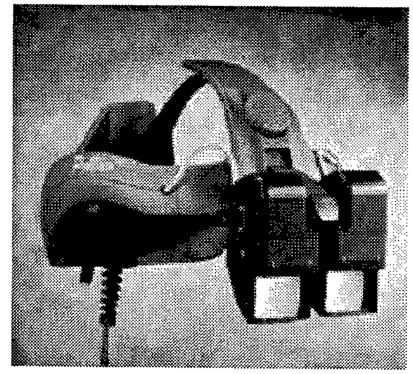

Figure 6. ProView display.

Embedded Eyeglasses Display. The MicroOptical Corporation has employed new fabrication technologies to support optical imaging embedded within small, lightweight displays such as eyeglasses (figure 7). This approach is still quite new and represents the current state of the art in small, head-worn designs. Working prototypes have been developed that allow presentation of images and data in eyeglasses (320 by 240 monochrome pixels) or a hand-held device (640 by 480 pixels). This display has generated significant interest in the military because potential users consider such eyewear acceptable, in the same sense that safety glasses and goggles are accepted (see figure 8).

Figure 7. Eyeglass display prototype.

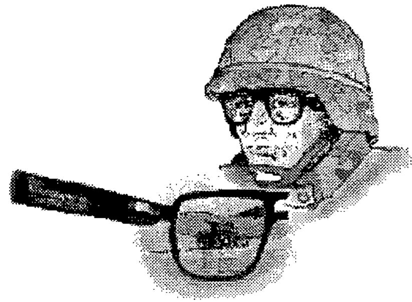

Figure 8. Eyeglass display concept.

INTERACTION METHODS

Interaction tools for control of portable visualization systems are diverse and mature enough to support the requirements of almost any field task. Miniaturized keyboards, keypads, and mouse tools are quite familiar to users of portable computer products, as mentioned earlier. In addition, pen or stylus-based tools and speech-recognition systems are becoming more common due to PDA popularity and the growing need for hands-free computer interaction in offices. More recently, some military applications with HMDs have added gesture control (i.e., computer interaction using hand and finger movements with specially instrumented gloves) to the set of operational input devices. Given the maturity of more conventional input devices, AITS project emphasis should probably be given to in-depth evaluation of gesture interaction, about which less is known.

PORTABLE INFORMATION ASSISTANTS

The technology review now extends to examples of portable diagnostic or decision support systems that integrate displays with data access and communications capabilities. This category of

interface device includes PDAs and tactical information assistants (TIAs). The distinction between these names is not always clear; portable assistants support hand-held data entry and retrieval, while the more powerful systems support complex information exchange and communications with remote sites. They are, therefore, much more than display devices, and some are even body-worn for use while performing other tasks. Note that most of the systems described here support some level of voice recognition for computer interaction, and that this performance is achieved with both 486 and Pentium-class processors.

Adtranz

Developed by Carnegie-Mellon University, the Adtranz is a pen-based, mobile computer with a 486 processor. The system has hard-disk storage, a digital voice radio, and a 640 by 480 pixel monochrome display, although a VGA head-mounted display is also available. The Adtranz (figure 9) can support voice, image and data transmission over a wireless local area network (LAN). The interface allows the user to access troubleshooting databases, to place bookmarks or enter data, and to collaborate with other maintenance personnel over the Internet.

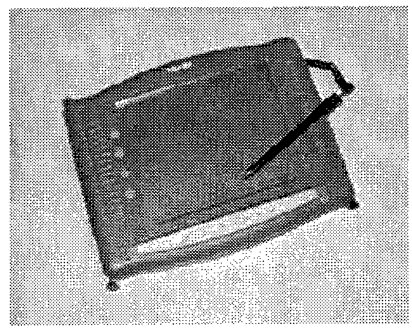

Figure 9. Adtranz.

Tactical Information Assistant–Prototype (TIA-P)

The TIA-P (figure 10) is a developmental system, also from Carnegie-Mellon University, designed to provide speech translation to the field soldier. Additional applications include maintenance, by providing the interface to electronic technical manuals and access to a home-base "help desk," and support for intelligence collection. TIA-P is a ruggedized, hand-held, pen-based system driven by a 100-MHz 486 processor, and has been field-tested in Bosnia and Korea with the Dragon speech-recognition system.

Figure 10. Tactical Information Assistant.

HUDset—Augmented Reality for Maintenance

An industry–university team led by Boeing has developed two head-mounted display systems to demonstrate the effectiveness of augmented reality for maintenance tasks. These systems are not commercially available. One system employs see-through, head-mounted displays to present diagrams and text stabilized over the real world, while another presents images of objects that cannot be directly seen, such as components inside an engine (e.g., figure 11). These displays, known as HUDsets (or, heads-up, see-through, head-mounted displays), permit hands-free access to data in support of aircraft repair operations. Project improvements include 640 by 480 pixels to

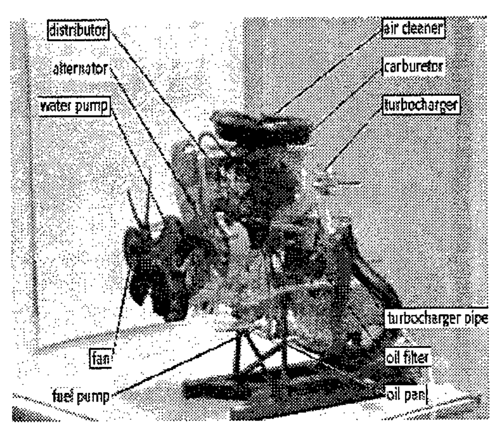

Figure 11. Augmented reality support.

1280 by 1024 pixel capability. Both systems perform head tracking to maintain registration between the graphical displays and the real-world scene. This is achieved with video-metric techniques (i.e., by imaging and tracking fixed position references in the environment). Because such references are essential for image registration, this approach is best-suited to indoor use.

INTEGRATED INFORMATION SYSTEMS

Additional versatility and physical size distinguish these systems from the Portable Information Assistants discussed previously. The devices presented here are more powerful in that they involve general as well as special-purpose computing capabilities, multiple input and control methods, and integrated head-mounted displays. Note that displays chosen for the representative systems below all belong in the 640 by 480 pixel class. While higher capabilities were discussed earlier, system designers have apparently opted for more practical and reliable alternatives. Functional performance, however, does not seem to have suffered.

Navigator 2

The Navigator 2 (figure 12) is a multimedia wearable computer for aircraft inspection and data recording. The system is used to support maintenance technicians in locating and designating cracks and corrosion on large aircraft. Navigator 2 employs a joystick to graphically designate discrepancies on two-dimensional diagrams of aircraft sections, and to select among text-based menu items to classify the nature of discovered problems. The system also supports database entry of discrepancies via speech input.

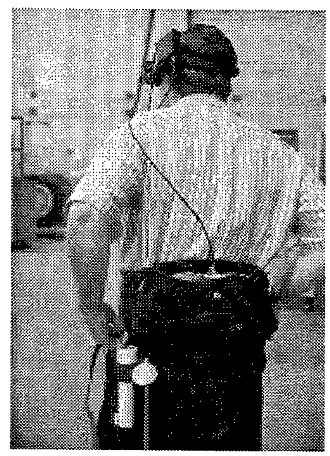

Figure 12. Navigator 2.

VuMan Series

VuMan is a set of four evolutionary information assistants (1, 2, 2R, and 3) developed at Carnegie-Mellon University. VuMan1 (figure 13) allows the user to maneuver through blueprints by using a three-button, belt-worn input device for maneuvering through information. Output is displayed on a commercial HMD. VuMan2 allows the user to select items from a map, an image database, or a text database using a cursor control. A variant of VuMan2 employs a rotary dial and push-button to allow the user to rapidly navigate through a large number of menu items. Both versions of VuMan2 have applications as maintenance assistants, with communications support to remote computers for data exchange. Applications can be changed by loading different EPROM memory devices into the available PCMCIA slots. VuMan3 upgrades the processor and memory and provides additional expansion capabilities.

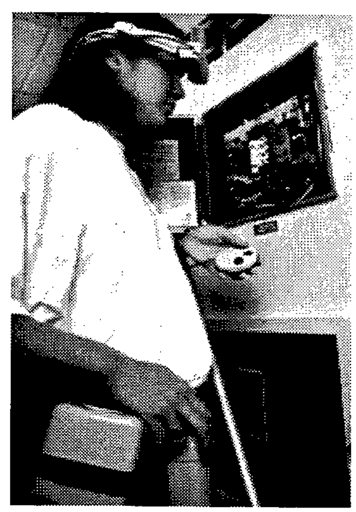

Figure 13. VuMan.

Mobile Assistant IV

This product is a wearable, voice-activated computer system available from Xybernaut Corporation (figure 14). The Mobile Assistant IV (MA-IV) is based on Pentium-class technology and can be equipped with up to 266-MHz MMX CPUs, 128 MB of RAM, and 6.0 GB of removable hard-drive storage in the belt-worn module. Information is presented on either a monocular (conventional or see-through) color VGA head-mounted display or an optional hand-held display. This product represents a good transition between the Portable Information Assistants and more complex wearable systems in that a variety of hardware and software applications can be configured using a range of PC card slots and external ports. The MA-IV can also be equipped with a GPS receiver and with equipment to support voice, data, and image transmission via wireless ethernet.

Figure 14. Mobile Assistant IV.

The Mobile Assistant IV is intended for a wide commercial market, including military customers, but is not tailored to any specific application.

Special Operations Combat Management System (SOCM)

SOCM is an integrated wearable computing and display system developed by a Boeing-led industry team as the soldier's link to the digital battlefield. The system, based on a 150-MHz Pentium CPU, has interfaces with a GPS, multiband radios, and a wireless LAN for voice and data exchange. Software and displays have been specially developed to support automated information management during military operations. The SOCM system features both a head-mounted display (figure 15) and an alternate hand-held display, both with 640 by 480 pixel capability. A miniature keyboard, designed for special operations use, has also been included. All components are ruggedized for field operations and are integrated into an adjustable vest intended for use over military clothing, including ballistic protection.

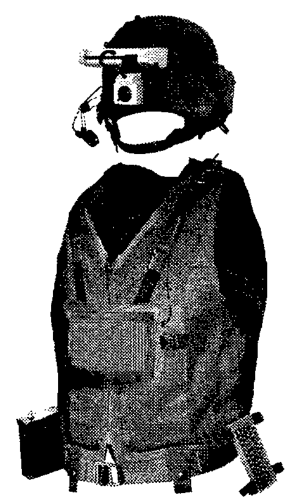

Figure 15. SOCM system.

SUMMARY

The development pace of interface devices encountered during the technology review was impressive. Computational power (e.g., 233-MHz Pentium II) and data storage capabilities (e.g., 6 GB) are affordable and adequate to support even ambitious applications of AITS. Furthermore, the practical use of multiple communications methods (e.g., analog and digital, LAN and wireless) and interaction tools has been demonstrated through a variety of university and industry projects. More than one technology choice is available for essentially every component of AITS.

The improvements in component capabilities, coupled with significant reductions in the physical size of these devices, have fostered an accelerating trend toward integrated devices, including total interface packages in hand-held or body-worn form. In particular, wearable computing systems are being produced commercially in an ever-wider range of models and prices.

The most rapid development appears to be taking place in the realm of small visual displays. Full VGA capability is available in both see-through and conventional systems, and in both hand-held and head-mounted forms. This is fortunate, as the visual display will drive the performance—and user acceptability—of the entire AITS system. However, the presentation formats for the AITS display have not yet been completed and will inevitably undergo evolution as a function of user testing. It is important, therefore, to maintain flexibility in the selection of display devices, and to consider a range of alternatives throughout the development effort, because the criteria for optimal information display may change over time.

BASELINE INTERFACE SYSTEM

The objective of this phase of the AITS program is to define and justify a baseline interface design appropriate for testing with security personnel. An initial set of hardware components and features can be identified based on the analyses of *information requirements* and *interface design principles* and on the results of the *technology review*. The baseline configuration necessarily reflects tradeoffs between task needs, technology capabilities, acquisition costs, and flexibility (i.e., the ability to modify the system based on user testing).

VISUAL DISPLAY

The two fundamental choices for visual displays appropriate for use by mobile personnel include hand-held (including laptop and palmtop computers, PDAs, etc.) and head-worn systems (including see-through and conventional displays). A head-mounted, see-through display (HMD) is selected for the initial AITS prototype because of the following factors:

1. It provides a hands-free method for conveying information to the user. The information surface is always available where the user can see it, without having to look down at a hand-held display, and the display can be moved out of the line of sight when not wanted. This approach seems most in keeping with the desires of the user communities examined for the AITS project.
2. Many integrated systems providing head worn displays—especially wearable computing outfits—also furnish hand-held displays as part of their equipment suite. This permits comparison of both approaches under the same task conditions.

A further choice among HMDs is made in favor of a monocular see-though device because of the following factors:

1. A see-through device does not fully occlude binocular vision, even when computer-generated information is being presented. Symbols and images are superimposed over the real world, yet the surrounding environment is still viewable.
2. Both eyes can view the world naturally, and peripheral vision cues are still available. Field-of-view is therefore less of a factor in designing the size of the display surface.
3. Since both eyes can see the environment, the display does not seriously interfere with normal stereoscopic vision.
4. The display can provide both registered (i.e., stabilized to the user's frame of reference) and/or unregistered information. Intrusion alerts can be presented where they actually are in the environment, without having to interpret positions information from a hand-held display to the real world.
5. A display of this type provides the same functionality as the Hand-Held and Body-Worn Graphical Display System (described in the Technology Review Section), permitting evaluation of many of the features of this hybrid approach with a single equipment configuration.

Because the *information requirements* analysis did not identify a need for stereoscopic presentation of images or symbols, a monocular display surface (i.e., covering only one eye) is considered sufficient to convey all necessary information for AITS applications. This approach has the additional advantages of reduced size, weight, complexity, and cost. Binocular see-through displays for stereoscopic presentation are available should user testing uncover a performance benefit for this approach.

In general, considerable performance gains are achievable from the use of color rather than monochrome displays (e.g., Sanders and McCormick, 1987). Color-coding of information, for example, could be used to classify the type of intrusion (e.g., dismounted soldiers, heavy vehicles, etc.) or the degree of potential threat, and color would certainly be useful for presentation of map information. However, the necessary supporting optics for color displays reduce the amount of ambient light that passes through to the user's eye, reducing visibility through the device. Nevertheless, color capability is considered necessary for the AITS prototype in order to evaluate its benefits. Evaluation of appropriately coded monochrome symbol sets will also be addressed during user testing to determine the relative degree of any performance gains from the use of color.

Requirements for display resolution will be largely determined through user testing, and the interpretability of alphanumeric symbols, maps, and raw sensor images will establish the final requirements. The prototype interface system should have the best possible capability, if only to determine where performance improvements asymptote. The tradeoff between display resolution and user performance gains cannot be accurately determined unless display capabilities can represent the high end of the available resolution range.

Alternate Display Methods

The alerting and orienting properties of directional auditory signals were discussed earlier (e.g., Deatherage, 1972). Cost and weight of headphones are certainly minimal and designs are available that do not block critical environmental sounds. However, equipment to generate and render directional audio signals (e.g., Sound Spatialization, 1999) has not been implemented in hardware suitable for use by mobile field personnel. While directional auditory displays are desirable for AITS, their use is deferred until characteristics and requirements of visual displays are better understood. Initial auditory signal implementations are limited to nondirectional cueing of intruder alerts.

Tactile displays can also provide useful directional and classification cues for intrusion alerts, or feedback about system inputs. Displays to support tactile information have been developed primarily at university research laboratories (e.g., Kawai and Tomita, 1996) and are usually available only in prototype form with limited technical support. Given the resource and scope limitations of the AITS project, these risks are considered sufficient to exclude tactile displays from the prototype interface suite.

SYSTEM INTERACTION TOOLS

Based on conclusions of the Functional Review section, ideal interaction tools for information support are those that are small, make minimal use of the hands, and do not require the soldier to look at the input device while it is being used. For these reasons, touchpads and stylus-based input devices were not selected for the initial AITS baseline design. In addition, analysis from the Interface Design Principles section has shown that AITS interaction tools will need to function effectively under the following conditions:

1. while performing mission tasks (e.g., carrying equipment, crawling on the ground, driving a vehicle, etc.);
2. operation in teams—specifically the configuration and management of communication nets with multiple people involved;
3. covert operations, when speech may not be desirable;
4. system effectiveness under high workload, when external noise, stress, and other factors reduce the accuracy of speech-recognition systems;

5. within the limits of what the soldier can remember (i.e., the vocabulary of function commands must be constrained to what can be mastered and remembered by users).

In general, these principles and test conditions make both voice and gesture interaction primary methods for the AITS prototype. It is unlikely that either mode will be satisfactory under all operating conditions, and therefore, the appropriate role of each will be determined as part of AITS evaluations.

Finally, both keyboard and mouse devices are included in the AITS baseline design, but only as system development tools (i.e., for laboratory configuration and testing), since they are not considered desirable for field use. While the operational disadvantages of keyboards and mouse devices were discussed previously, these appliances are excellent prototyping tools for concept testing and can, additionally, emulate certain features of other technologies such as chordic controls and touchpads, as necessary.

COMPUTING POWER AND SOFTWARE INFRASTRUCTURE

Most of the systems described in the Technology Review section—as well as other units surveyed but not included in this report—were implemented with 486-class processors. The more recent proliferation of Pentium-class processors has provided computing power that is more than sufficient for AITS requirements, and this is not considered a technology issue for the baseline system. A more important issue is the capability of a computer configuration to accommodate multiple peripheral devices; this issue will be the primary driver in equipment selection for the AITS design.

The choice of a software platform required more reflection. DOS, Windows 9x, Windows NT, and Linux all offered the features needed for software development and integration of special-purpose programs, although Windows NT and Linux offered particularly strong reliability. A decision was made to use Windows NT for development, based on the more extensive documentation and wider user base for this system.

SUMMARY

The AITS baseline design will consist of a wearable Pentium-class computer system and will include a monocular head-mounted display, with color and see-through capability. Voice control will be provided using a commercial package, and gesture control will be developed with a variety of resources, including in-house development. Additionally, a GPS receiver and a compass/tilt/roll module will be incorporated into the system to sense user location and head orientation. Finally, system functions will be constructed around a Windows NT software core.

Specific design features, including display metaphors and user testing results, will be reported in the second phase of AITS, which will cover interface design and validation.

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13. ABSTRACT *(Maximum 200 words)*

The Advanced Interface for Tactical Security (AITS) project was initiated to improve the task performance of security forces through technology and design improvements to information display systems. The project was implemented in three phases: (1) problem analysis and concept definition, (2) interface design and validation, and (3) communications tools development. This report contains the results of the first phase.

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